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Evaluation of Track-Etch (Trade Name) Detectors

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A study was conducted to evaluate the precision and accuracy of Track-Etch^{R} passive radon detectors manufactured by the Terradex Corporation. Four configurations of these detectors were exposed to known radon concentrations in the Eastern Environmental Radiation Facility radon chamber under varying exposure regimines and sent to Terradex for processing and readout. Data reported by Terradex and EERF's exposure concentrations were used to calculate calibration numbers for each configuration which were then compared to calibration numbers used by Terradex. Results of our study indicate that groups of detectors exposed together and processed together demonstrate similarity in response. Groups of detectors exposed and processed at different times, however, did not always agree with each other nor with published Terradex calibration numbers.

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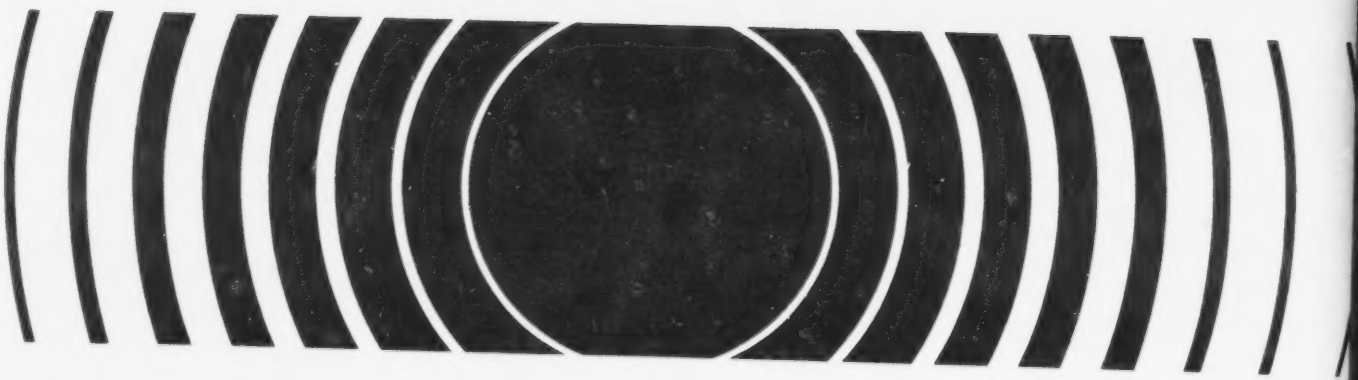

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Track-Etch® is a registered trade name for nuclear track detectors made by Terradex Corporation, Walnut Creek, California. Evaluation of this product by EPA does not constitute its endorsement by EPA. Throughout the paper any reference to "nuclear track detectors" are those manufactured by Terradex.

Evaluation of Track-Etch Detectors

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May 26, 1983

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Abstract

A study was conducted to evaluate the precision and accuracy of Track-Etch® passive radon detectors manufactured by the Terradex Corporation. Four configurations of these detectors were exposed to known radon concentrations in the Eastern Environmental Radiation Facility radon chamber under varying exposure regimines and sent to Terradex for processing and readout.

Data reported by Terradex and our own exposure concentrations were used to calculate calibration numbers for each configuration which were then compared to calibration numbers used by Terradex.

Results of our study indicate that groups of detectors exposed together and processed together demonstrate similarity in response. Groups of detectors exposed and processed at different times, however, did not always agree with each other nor with published Terradex calibration numbers.

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[R] Registered tradename.

Introduction

For the past several years the U.S. Environmental Protection Agency's Office of Radiation Programs (ORP) has been involved in several studies designed to assess ambient and indoor concentrations of radon and radon daughter products. The data gathered in these studies are being used in turn to help evaluate the health impact of population exposure to radon and its decay products and to determine the efficiency of remedial and preventative techniques.

Radon daughter measurements are relatively difficult due to several contributing factors: radon itself is a fairly unreactive noble gas that decays into particles having short half-lives and a great affinity for respirable airborne dust (condensation nuclei). Much scientific attention has been directed of late toward characterizing the relationship between radon and its decay products and developing techniques for sampling and measuring these quantities accurately under dynamic conditions. Several measurement techniques are now commonly used to measure both radon and daughter product concentrations with a fair degree of precision and accuracy. Radon is commonly sampled in evacuated scintillation cells and subsequently counted on photomultiplier tubes according to generally accepted procedures (Lu57, Ge76). The minimum detectable levels generally achievable by this method are about 0.1 pCi/liter. Other investigators draw air samples into glass flasks and metal containers and determine radon concentrations by a pulse ionization technique (Ha72). This procedure usually results in a lower detection limit of 0.05 pCi/l.

Variations on these measurement techniques have been incorporated by several equipment manufacturers into commercial devices with integrating flow-through characteristics and automatic sampling features. Radon daughter concentrations and subsequent WL determinations can be accomplished by drawing air samples through a filter and quickly counting the filter alpha activity. By using the techniques and assumptions of several investigators (Ku56, Th72, and Ha69), and applying alpha spectroscopy or gross alpha counting, sensitivities of .0005 WL. are possible. Long-term integrated samples in the field are accomplished with Radon Progeny Integrated Sampling Units (RPISU's) which employ thermoluminescent detectors to measure alpha activity trapped on filter membranes(Sc74). Automatic sampling and measurement devices for Working Level determination have been developed by Argonne National Laboratory (ANL78) and commercially by several companies. These are commonly known as Instant Working Level Monitors (IWLM).

In most cases, the procedures and equipment necessary to accomplish all of the aforementioned measurements are cumbersome, expensive (or both), generate heat and/or noise and require electrical power in the field. In addition, the techniques do not lend themselves well to large scale screening measurements or to extremely long (months or more) measurement time periods.

It is for these logistical and economic considerations that inexpensive and passive radon detectors are so attractive. The ORP has experience with two passive systems at the present time. The first is known as the Passive Environmental Radon Monitor (PERM) which is based on a design by George (Ge77). This device uses a battery to impose a voltage potential across a metal funnel and a center electrode bearing a thermoluminescent dosimeter chip (TLD). The alpha-emitting radon

daughter products exist as free positive ions which are attracted to and subsequently expose the TLD. The second type of passive detector which we have used is Terradex's Track-Etch® Detector. This detector consists of a material in which tracks are formed on bombardment by a alpha particle. When suitably processed and "developed" the tracks become visible, are counted microscopically, and are related to radon concentrations via an empirically derived calibration factor having units of tracks/square millimeter per pCi/liter-day.

Study Objectives

The objective of this study was to assess the accuracy and precision of the detectors as environmental radon monitors under several controlled exposure conditions. Field testing nuclear track detectors is an objective of a much larger environmental study currently in progress at Butte, Montana. Existing Terradex Track-Etch® data were statistically analyzed and the results formed the basis for designing a study to address the following issues:

1. Reliability; the extent to which different detectors from the same production lot yield similar results when exposed together.
2. Lot-to-lot variability; differences in detector response between 2 different production lots.
3. Linearity of response; consistency of detector response over a range of total exposures.

Our study evaluates detector response characteristics by exposure to known concentrations of radon and comparison of resultant calibration factors to published values. Terradex calibration factors were derived from exposure data sets that exhibited considerable variability. The statistical analysis of the results of this study consist of estimations rather than hypothesis testing.

Methodology

Detectors

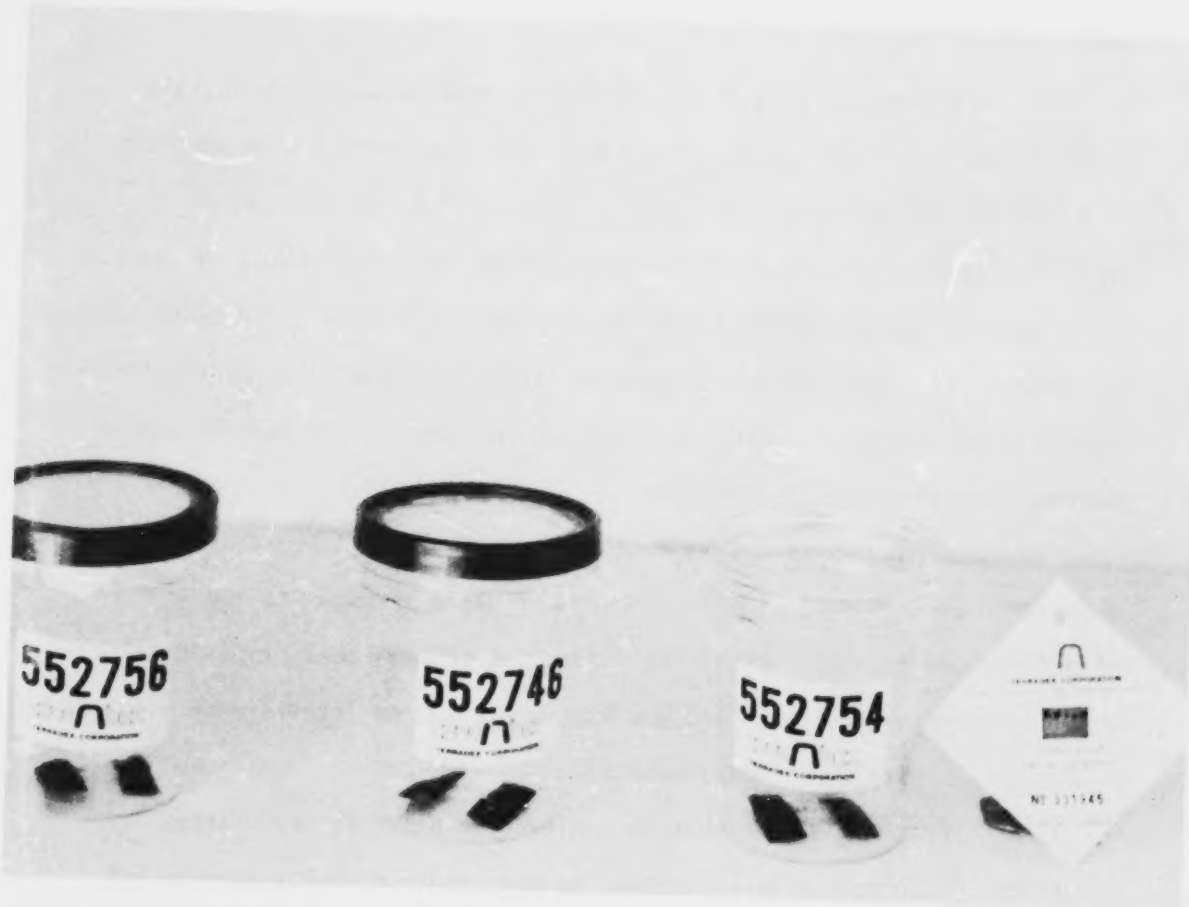
The detectors used were standard nuclear track detectors purchased from Terradex in four configurations: the filter cup, membrane cup, open cup and bare badge (see Fig. 1). The detectors are supplied by the manufacturer in the open cup and bare card configuration. The customer then assembles the required paper filter or membrane filter configuration with provided snap ring and filter materials.

The detectors are provided in differing configurations to satisfy varying sampling requirements or environmental conditions. The open cup is a plastic cup with the 0.8 x 2.5 x 0.2 cm plastic nuclear track detector fastened to the inside bottom with two strips of tape. Because it is open to the atmosphere, the open configuration detector responds to both radon and plated out radon daughter alpha activity. The manufacturer suggests that plate-out characteristics of the sampled environment may be derived from this type of detector.

The membrane cup is fitted with a clear, semi-permeable plastic membrane that retards the diffusion rate of gases through it. By virtue of differences in radiological half-lives, these membranes preferentially discriminate against thoron and are used where thoron interference might pose problems with radon measurements.

The filter cup is covered with a micropore paper filter which, according to the manufacturer, allows gaseous radon to enter the cup but blocks the passage of radon daughters. This configuration is preferred where radon is to be measured alone and thoron is not significant.

Figure 1



Four Configurations of nuclear track detectors

The bare badge configuration is simply the detector itself mounted on a 6.5 cm square card. This configuration is sensitive to radon and radon daughter products, but only responds to plate-out on the detector surface as compared to the open cup which responds to radioactivity on the walls of the cup as well.

The cup detectors are supplied by the manufacturer nested in aluminized plastic sleeves along with filter material, snap-ring filter retainers, data forms, etc. The bare badges are shipped individually packaged in glassine envelopes. After exposure, the detectors are returned to the manufacturer where they are processed and read. Exposure data is then returned to the customer.

Radon Exposure Chamber

The EERF radon chamber was constructed on site of 1/2-inch plywood supported by an aluminum frame (Fig. 2). The overall dimensions of the chamber are 1.2 x 1.2 x 2.4 meters. A door allows placement and removal of measuring instruments. A passbox allows loading of small instruments, detectors, and filters without disturbing the environment in the chamber. A rubber glove port allows manipulation of devices in the chamber, and twelve sampling ports with flow rate meters allow direct air sampling from inside the chamber.

The EERF chamber is a continuous flow design. The radon-222 source used in the chamber consists of selecting one of three gas-washing bottles containing 25 μCi, 100μCi and 400μCi respectively, of radium-226 in solution. The appropriate source is selected for the chamber concentration desired. Each μCi of radium-226 generates approximately 126 pCi of radon-222 per minute. The radon is harvested from the radium

Figure 2

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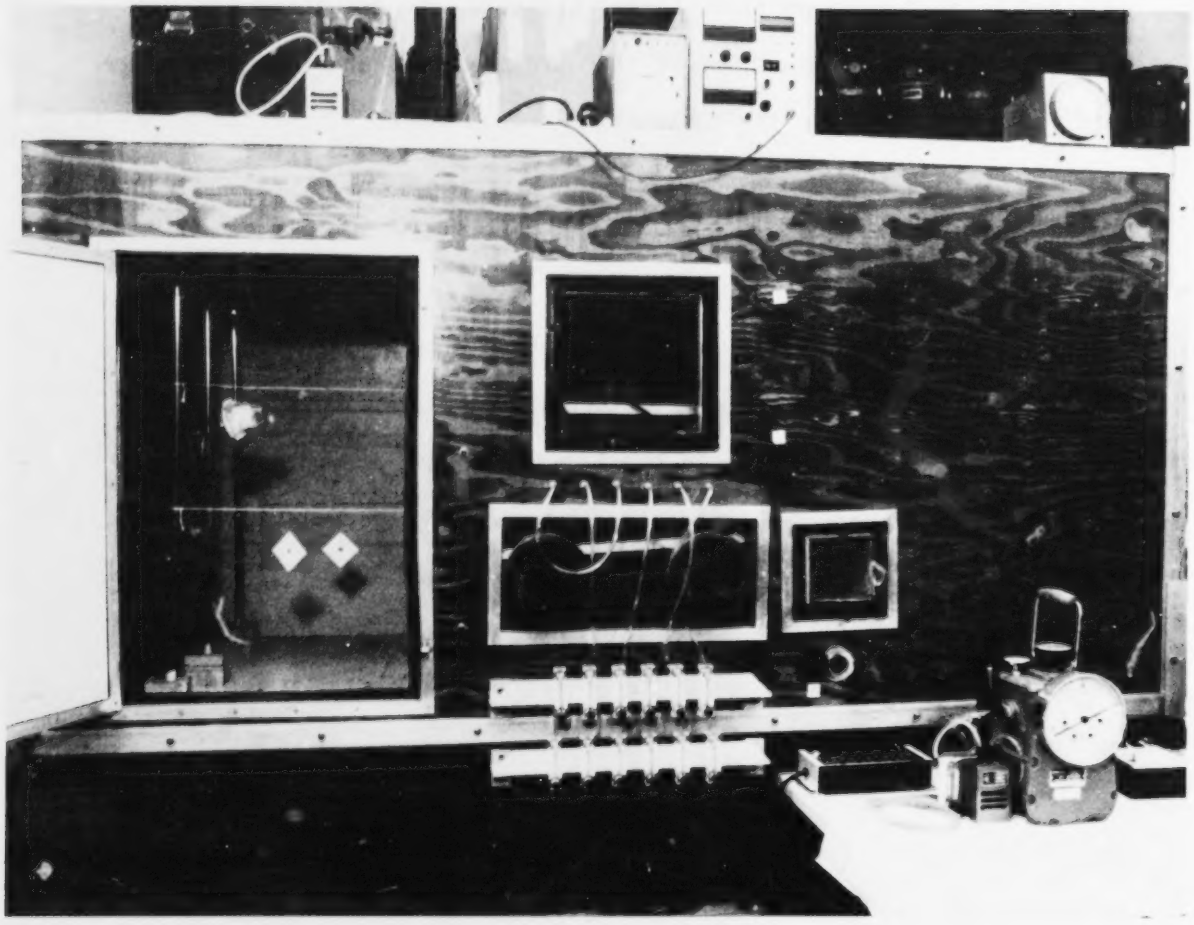

EERF Radon Calibration Facility

solution by air bubbled through the solution at about 1 liter per minute. The radon enriched air flows through traps and filters to remove any inadvertent particulate radium carry-over, and then into a 20-liter aging bottle which allows 20 minutes of radon daughter in-growth time before release into the chamber. Final chamber concentrations of radon are maintained by dilution with room air, which is normally controlled between 50 and 200 liters per minute. Condensation nuclei are added to the dilution air supply by a voltage-controlled nichrome heating wire. An automatic air humidifier keeps relative humidity at approximately 80 percent. Diffuser panels inside each end of the chamber accomplish homogeneity of radon concentration in the chamber. Having passed through the chamber, the radon exhausts through a wall into a large empty room which serves as a buffer against turbulence. From this room it is exhausted to the outside by a fan.

Exposure Measurements

Concentrations of radon-222 in the chamber were determined by twice-daily grab samples in scintillation cells calibrated with known quantities of radium-226. Radon was also monitored continuously with calibrated flow-through radon detectors with integrated count totals printed out hourly.

Working levels were determined by twice-daily grab samples of filtered air with concentrations calculated according to a Modified Tsivoglou technique (Th70) or an alpha spectroscopy technique (Ma69). The alpha counter used is calibrated with a reference source of known activity. In addition, the EERF hosted an interlaboratory radon/daughter measurement conference in September, 1981, in which representatives from

the Bureau of Mines, Environmental Measurements Laboratory, Oak Ridge National Laboratories, Argonne National Laboratory, Mound Laboratory and Lawrence Berkeley Laboratory participated in intercalibration measurements. All EERF radon exposure data have been corrected to the calibrated values obtained during the exercise. These corrected radon values, then, are the "true" radon values used in this study against which the values reported by Terradex are compared. Stability and statistical characteristics of our radon data are presented in the Results section of this report.

Condensation nuclei concentrations were monitored with an Environment One Model Rich-100 Condensation Nuclei Counter and the data recorded on a strip chart recorder.

Temperature and humidity were measured with standard gauges mounted inside the chamber, with values recorded manually each day.

Exposures Protocol

For each exposure, the desired concentration of radon was selected and allowed to stabilize in the chamber as determined by a flow-through detector and scintillation cell measurements. Detectors for the experiment were then introduced into the chamber through the passbox and suspended on a three-dimensional string matrix such that approximately .3 meters of free space surrounded each detector (Fig. 3). The detectors were left in the chamber long enough to accumulate the desired exposure and were then removed, packaged according to the manufacturer's instructions, and shipped to the manufacturer for processing.

Figure 3

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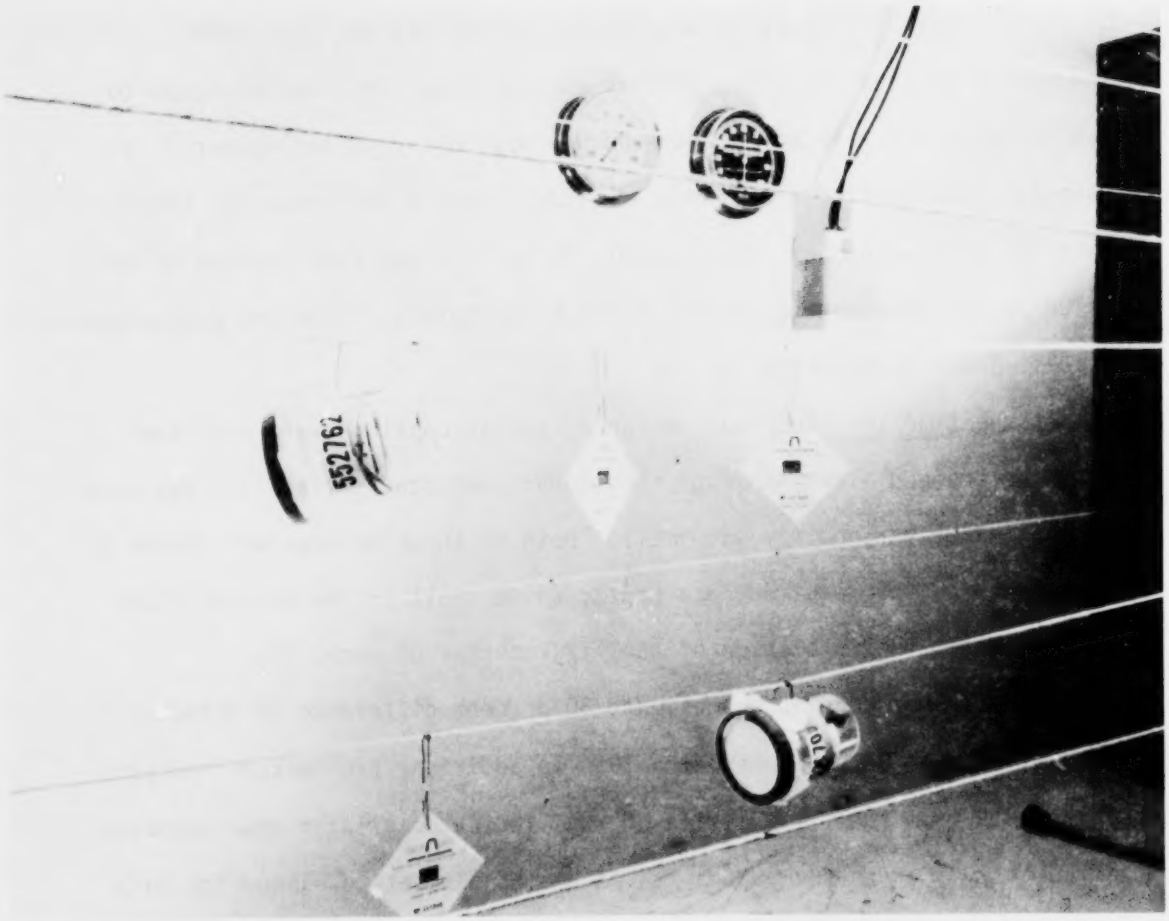


Detectors Deployed in Exposure Chamber

The exposure protocol required two series of runs, each series consisting of one run for 10 days at 100 pCi/liter, one for 20 days at 50 pCi/liter, and one for 40 days at 25 pCi/liter, thus delivering the same total exposure in three different exposure patterns. The entire series of runs for all three exposures was repeated and constituted the second series of runs. In addition, linearity of detector response was determined by sequentially removing selected detectors from the exposure chamber during one of the exposure runs.

Once radon concentration in the chamber had stabilized and been determined, exposure duration was altered to deliver the cumulative exposure of as near to 1000 pCi/l-day as possible. This was designed to test the accuracy with which the exposure was delivered and measured, an essential component of a calibration study. During each run, the chamber contained various numbers of detectors in each of the four configurations, including for each configuration at least one detector from two production batches, Batch 8 and Batch 10.

At the time the study was designed, two assumptions were made that had to be changed midway through the study: detector reliability was good and lot-to-lot variability was small. Both of these assumptions tended to keep the number of required data points quite small in the initial study design. After the initiation of the first series of runs, the manufacturer announced an approximate 30 percent difference in detector response between Batch 8 and Batch 10. In addition, preliminary analysis of the data from the first series of runs indicated greater than expected variability. For these reasons it was deemed prudent to expand the data base during the second series of runs, and, consequently, more detectors

of each kind were exposed. Table 1 summarizes the numbers of detectors of each type used in each series of exposure runs, Table 2 summarizes the exposures achieved for the various stages of this study.

The final design-related item of note involved the selection of detector area to be read. The manufacturer offers three standard choices: 1 mm^2, 5 mm^2, or 15 mm^2, with respectively increasing sensitivity due to statistical resolution. It was expected that difficulty in maintaining exposure levels would dominate the overall error, and for that reason the sensitivity associated with the 5 mm^2 service was judged adequate. All detectors used in this study had 5 mm^2 read.

Table 1. Number of Detectors Used

A. 1st Series

Configuration(a) Nominal Exposure Length (days)	Lot 1 (Batch 8) F	M	O	B	Lot 2 (Batch 10) F	M	O	B
40	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1

B. 2nd Series

Configuration(a) Nominal Exposure Length (days)	Lot 1 (Batch 8) F	M	O	B	Lot 2 (Batch 10) F	M	O	B
40	4	4	4	2	4	4	4	4
20	4	4	4	2	4	4	4	4
10	4	4	4	2	4	4	4	4

(a) F = Filter cup.
M = Membrane cup.
O = Open cup.
B = Bare Card.

Table 2. Actual Delivered Exposures

Purpose	Rn Concentration (pCi/l)	Duration (days)	Total Exposure (pCi/liter-day)
Calibration	110.00	9	990.0
Calibration	98.84	10	988.4
Calibration	55.12	18	992.2
Calibration	50.91	20	1018.2
Calibration	26.90	38	1022.2
Calibration	26.09	38	991.4
Linearity	110.70	3	332.1
Linearity	109.80	6	658.8
Quality Control	110.00	9	990.0

Results

Chamber Stability

Exposure characteristics throughout the study were excellent. Flow-through samples with integrated hourly count totals in conjunction with twice-daily scintillation cell grab samples were used to verify concentrations in the chamber. Average concentrations and one standard deviation indicated less than five percent variation in radon concentration over all exposure runs. Details of quality assurance procedures for the EERF radon chamber are available separately (EPA82). Radon concentration data produced by the EERF flow-through detector radon concentrations were used with track densities reported by the manufacturer to calculate calibration factors.

Calibration Factors

A summary of all calibration factors determined during the study are shown in Table 3. For purposes of clarity it is noted again here that each series is composed of three runs each (10, 20, and 40 day exposures). The average calibration factor for all detectors of each type and batch in each series is compared to the manufacturer's reported calibration factors in Table 4.

The data in Table 4 indicate that the variation in calibration factors for the first series of runs ranged from a percent relative standard deviation of 6.9 percent (bare configuration, Batch 10) to 31.2 percent (membrane configuration, Batch 10).

Variation in the second series of runs was also higher, ranging from 12.2 percent relative standard deviation (bare configuration, Batch 10) to 34.1 percent relative standard deviation for the open configuration, Batch

Table 3. Summary of Calibration Factors (Tracks/mm^2 per pCi/liter-day

Nominal Exposure Length	10 Days		20 Days		40 Days	
Configuration/ Batch	1st[a] Series	2nd[b] Series	1st Series	2nd Series	1st Series	2nd Series
F8	.0295	.0207 ± .0025%	.0257	.0201 ± .0009%	.0321	.0193 ± .0015%
F10	.0283	.0584 ± .0198%	.0340	.0547 ± .0104%	.0441	.0438 ± .0049%
B8	.0728	.0490 ± .0014%	.0496	.0417 ± .0036%	.0576	.0582 ± .0009%
B10	.0956	.0734 ± .0071%	.0832	.0686 ± .0059%	.0882	.0821 ± .0037%
M8	.0121	.0114 ± .0011%	.0116	.0135 ± .0011%	.0153	.0133 ± .0021%
M10	.0135	.0195 ± .0032%	.0173	.0225 ± .0035%	.0249	.0276 ± .0054%
08	.0610	.0324 ± .0022%	.0368	.0349 ± .0025%	.0634	.0349 ± .0041%
010	.0656	.1046 ± .0425%	.0573	.1019 ± .0227%	.0699	.1032 ± .0329%

(a) Numbers in the 1st series are single data points and appear without error terms.

(b) Calibration factors are average of all data points in each category. Error term equals one standard deviation.

Table 4. Manufacturer Calibration Factors

	1st Series (N=3)	2nd Series (N=12)	Reported by Manufacturer (A181)
F8(b)	.0291 ± .0032 (11%)	.0200 ± .0019 (9.7%)	.0372 ± 16%
F10	.0355 ± .0080 (22.5%)	.0523 ± .0157 (30.0%)	.0484 ± 16%
B8	.0130 ± .0020 (15.4%)	.0127 ± .0019 (14.9%)	.0223 ± 26%
M10	.0186 ± .0058 (31.2%)	.0232 ± .0058 (25.0%)	.0290 ± 26%
08	.0537 ± .0147 (27.3%)	.0341 ± .0034 (9.9%)	.0562 ± 22%
0	.0643 ± .0064 (9.9%)	.1032 ± .0352 (34.1%)	.0731 ± 22%
B8	.0600 ± .0118 (19.6%)	.0496 ± .0090 (18.1%)	.0891 ± 20%
B10	.0890 ± .0062 (6.9%)	.0747 ± .0091 (12.2%)	.1158 ± 20%

(a) Midway through the study, the manufacturer reported an approximate 30 percent increase in Batch 10 sensitivity which is reflected in the Batch 10 calibration factors.

(b) F = Filter configuration
B = Bare configuration
M = Membrane configuration
0 = Open cup configuration

Error terms = one standard deviation.

10. Of the 16 average calibration factors determined, vary significantly from the manufacturer's reported values, the variability distributed mostly among configurations and batches, in the second series.

In comparing the first series averages with the second series averages, the first series was higher (range 2 percent to 57 percent) in 5 of 8 cases. The first series averages were lower (range 20 percent to 38 percent) in the remaining 3 cases.

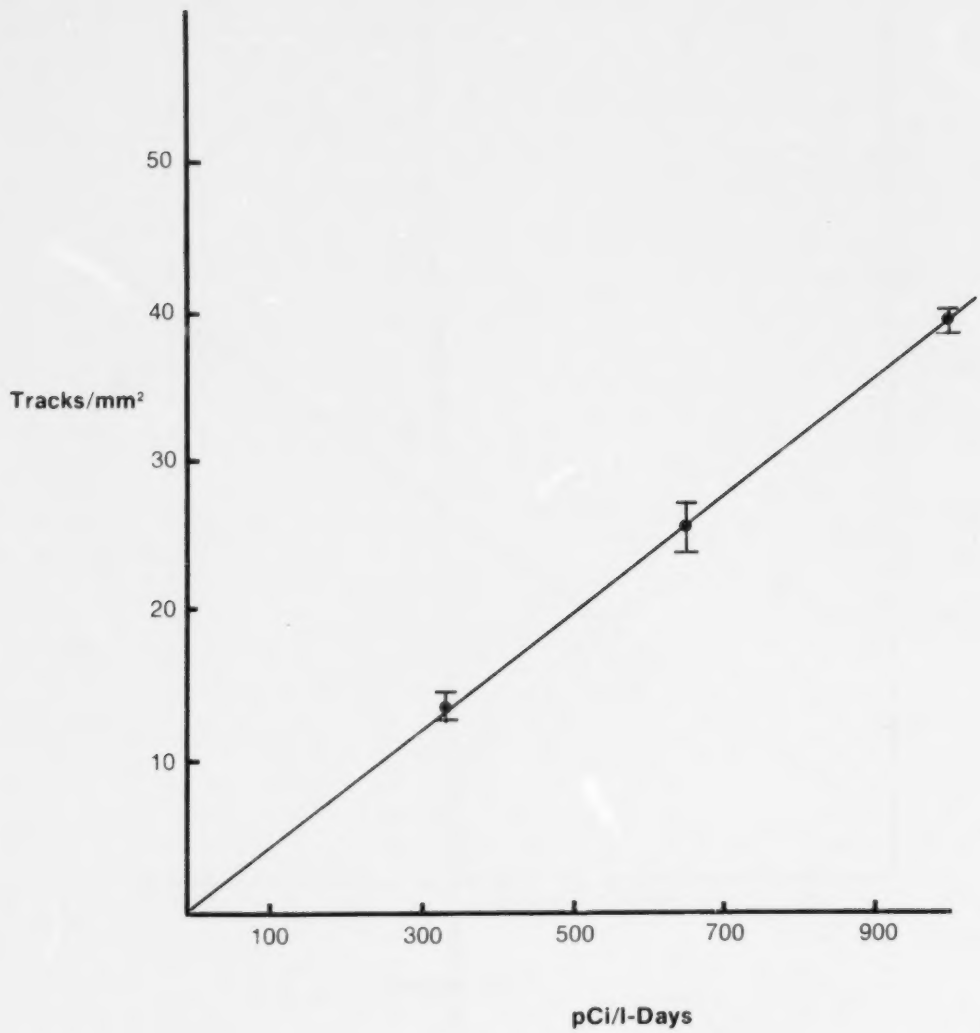
Lot-to-Lot Variability

Batch 10 detectors showed an increased sensitivity in all cases, thus confirming the manufacturer's report. In most cases, however, the degree of sensitivity increase was substantially greater than the reported 30 percent.

Linearity

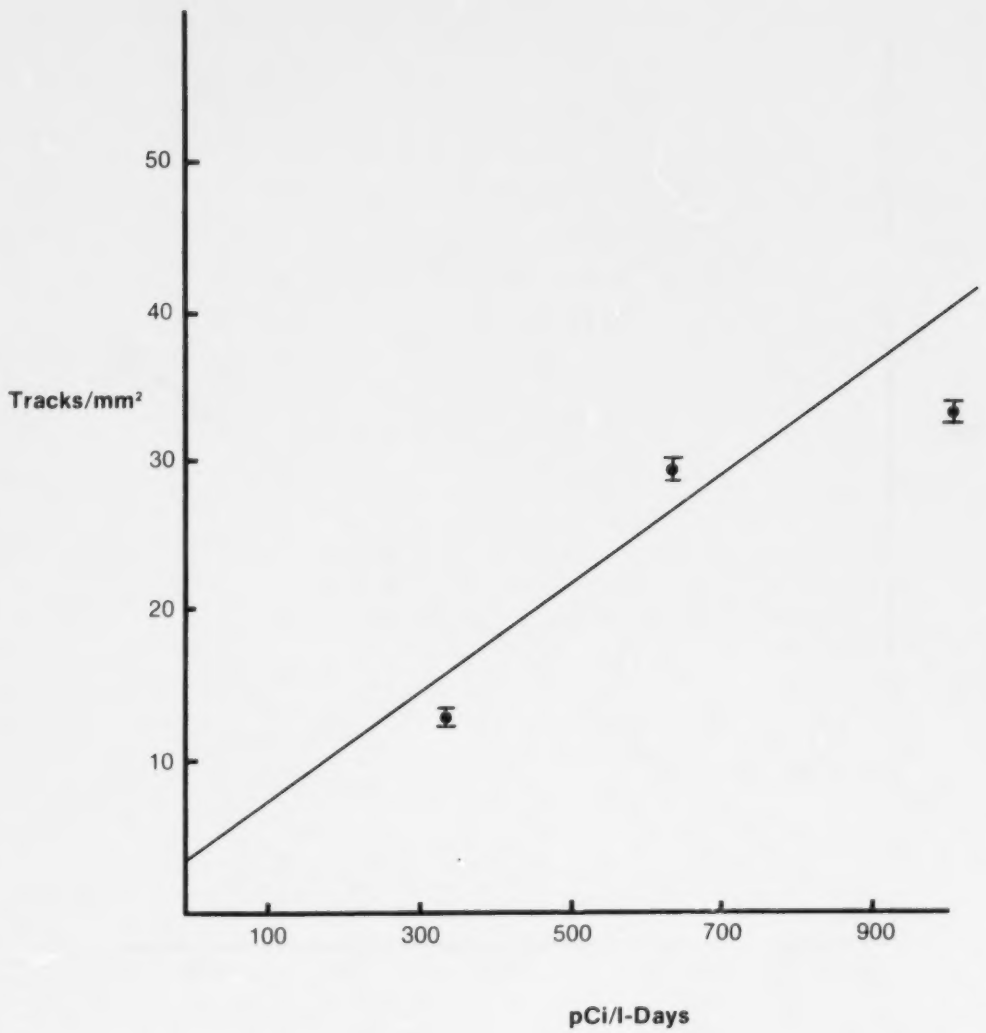
Linearity of detector response over the range of total exposure was seen for both the filter and open configurations. Figs. 4-7 show this linearity and the linear regression analysis of each batch (lot) and configuration. Filter detectors showed a slope of .03955 (coefficient of correspondence = .99805) and .03055 (coefficient of correspondence = .9350) for Batch 8 and Batch 10, respectively. The open configuration detectors showed slopes of .06309 (coefficient of correspondence = .98110) and .07200 (coefficient of correspondence = .98890) for Batch 8 and 10, respectively. The error bars on the data points represent one standard deviation. Each data point is the average of 2 detectors. The linearity portion of the study was done with a minimum of data points but was designed to reveal any anomolous non-linearities which could have affected other areas of the study. No such anonalies were found.

Figure 4



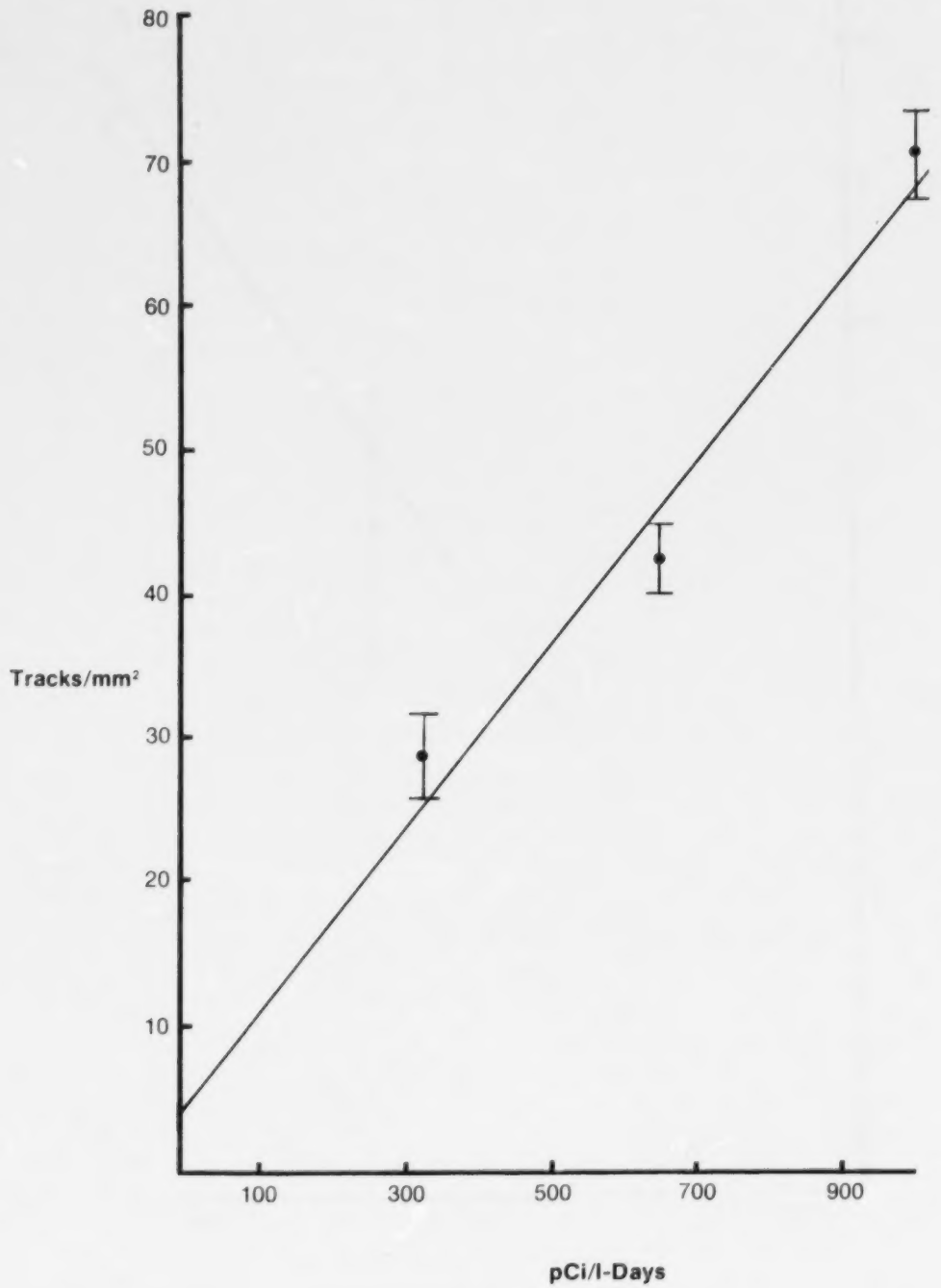
Linearity Plot for Batch 8 Filter Detectors

Figure 5



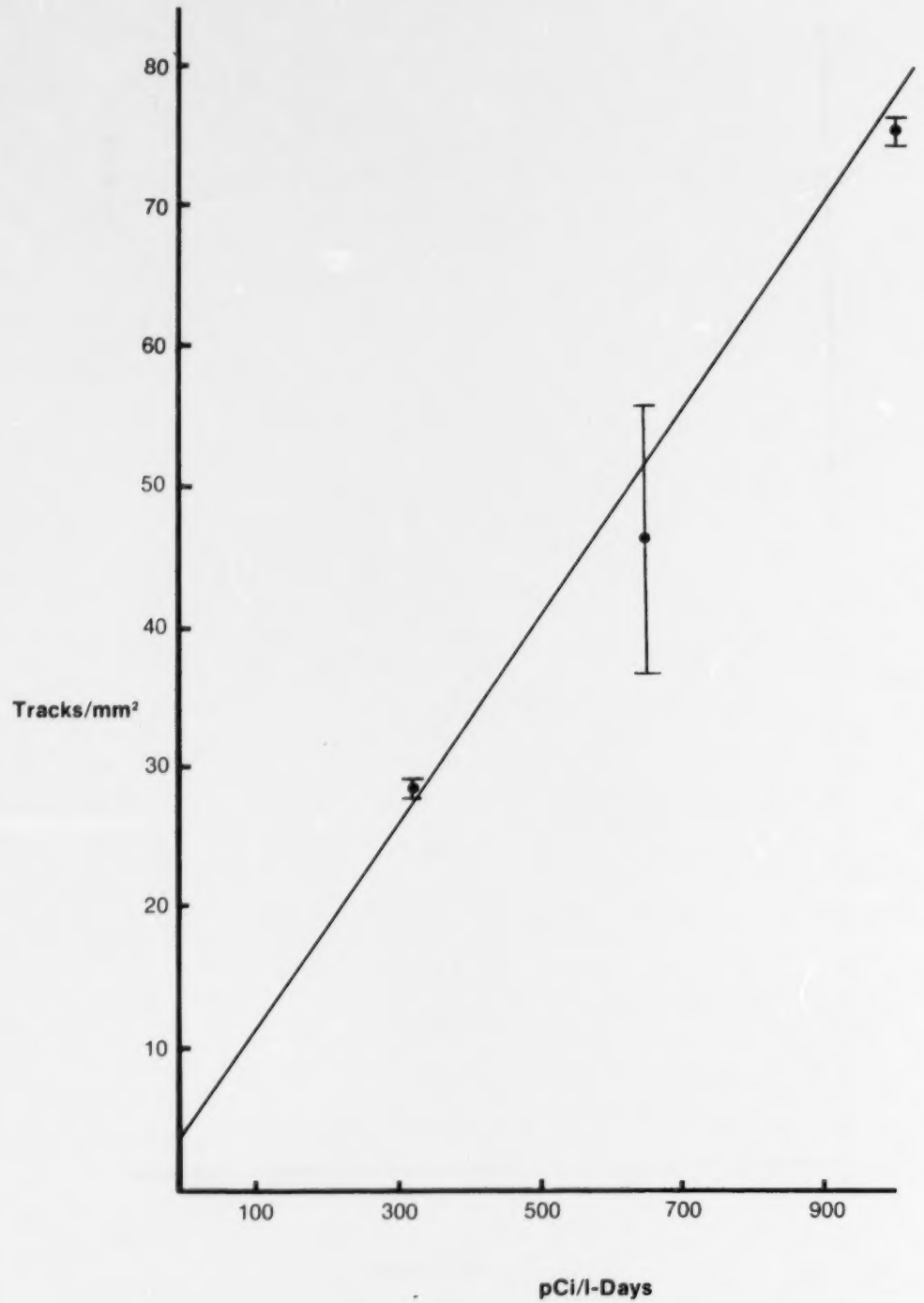
Linearity Plot for Batch 10 Filter Detectors

Figure 6



Linearity Plot for Batch 8 Open Detectors

Figure 7



Linearity Plot for Batch 10 Open Dosimeters

Quality Control

Twenty Batch 8 filter configuration detectors exposed together during the first run were divided into two groups (5 and 15), each submitted for processing and read out at a different time. Approximately six months separated the processing of the two groups.

The calibration factor for the first group was .0359 $\pm$ .0016 and the calibration factor for the second group was .0224 $\pm$ .0057, a decrease of about 38 percent.

Conclusions

The results of this evaluation tend to support the conclusion that detectors exposed together and processed together will yield good statistics. The calibration factors seen in Table 3 indicate that there is no apparent affect of length of exposure on detector response. If not processed together, the detectors exhibit a rather large and randomly distributed variability as shown in Table 4. If coupled with a precise determination of appropriate calibration factors (in one's own calibration chamber), the detectors should prove useful over the range of exposures used in this study. Also, our data indicate linearity of detector response.

It was recognized at the beginning of the study that the detectors respond not only to Rn-222 but also to radon daughter product alpha particles (Po-214, Po-218). The bare detector configuration and probably to some extent the open cup configuration would be expected to exhibit some variability in response due to daughter product plate-out on detector

surfaces. Working level equilibrium conditions during exposures would then impact the response of those detectors. No attempt was made to rigidly control the equilibrium conditions during exposure runs but random grab samples throughout the study consistently indicated an approximate 50 percent equilibrium condition.

The unpredictable variations exhibited between exposure runs, however, underscore the necessity for using the detectors with stringent calibration and quality control techniques.

The differences in lot-to-lot sensitivity are significant and must be considered when use of the detectors may involve more than one production lot.

Differences in many factors - chamber equilibrium, exposure levels used, cup manufacture, detector processing and reading - could conceivably explain differences between first and second series of runs. It is perhaps worth noting that the results in this study are similar to results previously reported by the manufacturer in that results within a run were very consistent, but results between runs were not. Further study should be designed to delineate the source of variability in these detectors, particularly at lower exposures levels.

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